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Specification and Drawings, as originally filed, with Application for Patent Serial No: **2,450,425**, on December 2, 2003, by **KARIM S. KARIM**, for "High Dynamic Range Active Pixel Sensor Architecture for Digital Imaging".

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Abstract of the Disclosure

A high dynamic range active pixel sensor architecture for digital imaging comprises a detector and a readout circuit. The detector is integrated with the readout circuit and the readout circuit has a plurality of transistors. The readout circuit is either embedded under the detector to provide a high fill factor or fabricated co-planar with the detector to reduce process complexity. A signal charge is accumulated on a pixel capacitance during an integration mode and is transferred to external electronics for data acquisition via a readout circuit during a readout mode. A pixel amplifier in the readout circuit is multiplexed to both amplify low level signals and to read out the input voltage when higher level signals are detected. The pixel amplifier in the readout circuit amplifies an on-pixel sensor input signal to improve noise immunity of sensitive sensor input signals to external noise sources together with a fast pixel readout time.

HIGH DYNAMIC RANGE ACTIVE PIXEL SENSOR ARCHITECTURE FOR DIGITAL IMAGING

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to a digital imaging system, and in particular, to a high dynamic range digital imaging pixel that can switch between large and small input signal image acquisition modes. For example, in diagnostic medical x-ray imaging applications, general digital radiography (including mammography) and low-exposure fluoroscopy, are large and small input signal modalities respectively.

2. Description of the Prior Art

Active matrix flat-panel imagers (AMFPIs) have gained considerable significance in digital imaging, and more recently in diagnostic medical imaging applications, in view of their large area readout capability. The pixel, forming the fundamental unit of the active matrix, consists of a detector and readout circuit to efficiently transfer the collected electrons to external electronics for data acquisition. The pixel architecture most commonly used for large area X-ray imaging is the passive pixel sensor (PPS) shown in Fig. 1. Here, a detector (e.g. amorphous selenium (a-Se) based photoconductor or Cesium Iodide (CsI) phosphor coupled to an amorphous silicon (a-Si:H) p-i-n photodiode) is integrated with a readout circuit comprising an a-Si:H thin-film transistor (TFT) switch. Signal charge is accumulated on the pixel capacitance (which is either the p-i-n photodiode capacitance or an integrated storage capacitor for the a-Se photoconductor arrangement) during the integration period and is transferred to an external charge amplifier via the TFT switch during readout.

While the PPS has the advantage of being compact and thus amenable to high-resolution imaging, reading the small output signal of the PPS for low input, real-time, large area applications (e.g. fluoroscopy) requires high performance charge amplifiers. These charge amplifiers can potentially introduce noise that degrades the signal-to-noise ratio (SNR) at low signal levels thus undermining the pixel dynamic range. In particular, fluoroscopy is one of the most demanding applications for flat-panel imaging systems and relates to real-time readout. Real-time x-ray imaging or fluoroscopy is used in many medical interventional procedures where a catheter is moved through the arterial system under x-ray guidance. The technical challenge to be addressed for fluoroscopy is the need for extremely low noise, or alternatively, an increase in signal size before readout. Studies on a-Si:H PPS pixels suggest that an improvement in signal to noise ratio of an order of magnitude is desirable in order to apply these systems to more advanced imaging applications.

One approach reported to increase signal-to-noise ratio is to employ in-situ (pixel) amplification via an a-Si:H current-mediated active pixel sensor (C-APS) as depicted in Fig. 2. Here, the RESET transistor resets the pixel while the READ transistor is used to readout each pixel. The charge gain of the C-APS circuit is programmable via the transconductance of the AMP TFT, the integration time of the charge amplifier and the sensor capacitance. Gain, linearity and noise results reported show promise and indicate that the a-Si:H C-APS, coupled together with an established X-ray detection technology such as a-Se or CsI/p-i-n photodiodes, can meet the stringent requirements for digital X-ray fluoroscopy.

A primary concern with the C-APS circuit is the presence of a small-signal linearity constraint at the X-ray input. Using such a pixel amplifier for real-time fluoroscopy (where the exposure level is small) is feasible since the voltage

change at the amplifier input is also small (in mV). However, in digital chest radiography or mammography, the voltage change at the amplifier input can be much larger (in V) due to the larger X-ray exposure levels, which causes the C-APS pixel output to be non-linear thus reducing the pixel dynamic range. Another consequence of a non-linear pixel transfer function is that the standard correlated double sampling mechanism cannot be implemented in hardware. Double sampling is required to correct for the effect of process non-uniformities (in the form of offsets) and, in the case of a-Si:H technology, transistor stability on pixel circuit performance.

The most striking shortcoming about the C-APS pixel is that the presence of a large output current in the AMP and READ transistor branch will cause the external charge amplifier to saturate. This becomes a concern when the C-APS is to be used for static radiographic applications (chest radiography, mammography) where the X-ray input and pixel output currents are both large. To implement both static and dynamic X-ray imaging, a pixel architecture capable of sensing a wide range of X-ray input signals is necessary.

SUMMARY OF THE INVENTION

Accordingly, it is an objective of the present invention to provide a high dynamic range active pixel sensor architecture for digital imaging that is capable of amplifying sensitive sensor input signals to improve their noise immunity to external noise sources with a fast pixel readout time. Concurrently, the high dynamic range active pixel sensor architecture is capable of reading out larger radiographic mode pixels with a fast pixel readout time.

In order to achieve the above objectives, the high dynamic range active pixel sensor architecture in the present invention comprises a detector for generating photo-carriers and discharging a certain level of induced voltage with an input signal; and a readout circuit for outputting a current with respect to the induced voltage.

Preferably, the detector is either an amorphous selenium(a-Se) based photoconductor or a CsI phosphor coupled to an a-Si:H p-i-n photodiode.

Further, the readout circuit has a plurality of thin-film transistors, the plurality of thin-film transistors is three thin-film transistors, one of which forms part of a source follower circuit for producing an output current or voltage with respect to an input signal voltage.

The readout circuit can be embedded under the detector to provide a high fill factor or be co-planar with the detector to reduce process complexity. The readout circuit produces the output current through a reset, integration and readout mode operation sequence.

BRIEF DESCRIPTION OF THE DRAWINGS

The above objective and other features of the present invention will become more apparent by describing a preferred embodiment thereof with reference to the attached drawings, in which:

Fig. 1 shows a passive pixel sensor (PPS);

Fig. 2 shows a current mediated active pixel sensor (C-APS); and

Fig. 3 shows a high dynamic range active pixel sensor architecture according to an implementation of the present invention.

DETAILED DESCRIPTION OF THE PREFERRED IMPLEMENTATION

The high dynamic range active pixel sensor architecture is shown in Fig. 3. Here, during the small, noise vulnerable, input signal acquisition mode (i.e. fluoroscopy), the circuit behaves as the circuit shown in Fig 2 where there is a reset, integrate and readout cycle. During this mode, the external reconfigurable amplifier is set to operate as a low noise

charge integrator (see Fig. 2) and the column load circuitry (shown in Fig. 3) is disconnected from the column. During reset, the RESET switch is turned ON to initialize the sensor integration node (READ switch is kept OFF). During integration, photon generated charge in the sensor causes a charging or discharging of the sensor node depending on the type of sensor. During integration, the READ and RESET switches are kept OFF. During readout, the READ switch is pulsed ON and a current proportional to the induced sensor charge is output on the array column and the output current is integrated by the column charge amplifier.

For pixel operation where larger inputs can occur (i.e. static chest radiography or mammography), the pixel level circuitry is operated in a similar reset, integrate and readout cycle as before. However, at the column level, the column load circuitry (shown in Fig. 3) is activated. The column load circuit usually comprises of a thin film transistor operating in saturation to convert the pixel output current into a voltage although other implementations are also possible. With the addition of the column load circuit, the pixel circuit becomes a voltage source follower amplifier that exhibits large signal linearity. During integration, photon generated charge in the sensor causes a charging or discharging of the sensor node. During integration, the READ and RESET switches are kept OFF. During readout, the READ switch is pulsed and the photon induced voltage change at the sensor node is transferred to the column load circuitry. This pixel output voltage on the column is further amplified by the reconfigurable external amplifier which now operates as a voltage amplifier circuit.

By switching between current mediated and voltage mediated modes of operation, the pixel can be used as an amplified pixel for small, noise-vulnerable input signal applications like X-ray fluoroscopy and as a voltage source follower for higher input, imaging applications like X-ray chest radiography or mammography. Since the pixel output

transfer function is inherently linear for the V-APS in large signal radiographic mode and the C-APS in small signal fluoroscopic mode, the effect of non-uniformities in the imager fabrication process and/or a-Si TFT instability can be mitigated by standard correlated double sampling and offset-and-gain correction techniques commonly applied in imaging. The high dynamic range active pixel sensor architecture of Fig. 3 is suitable for implementation in a-Si:H, polycrystalline silicon (poly-Si) and other related technologies. The high dynamic range active pixel sensor architecture can be interfaced to commercial or custom designed, external column amplifiers or even be interfaced to suitable on-panel fabricated column amplifiers.

Although the preferred embodiments of the present invention have been described, it will be understood by those skilled in the art that the present invention should not be limited to the described preferred embodiments, but various changes and modifications can be made within the spirit and scope of the present invention as defined by the appended claims.

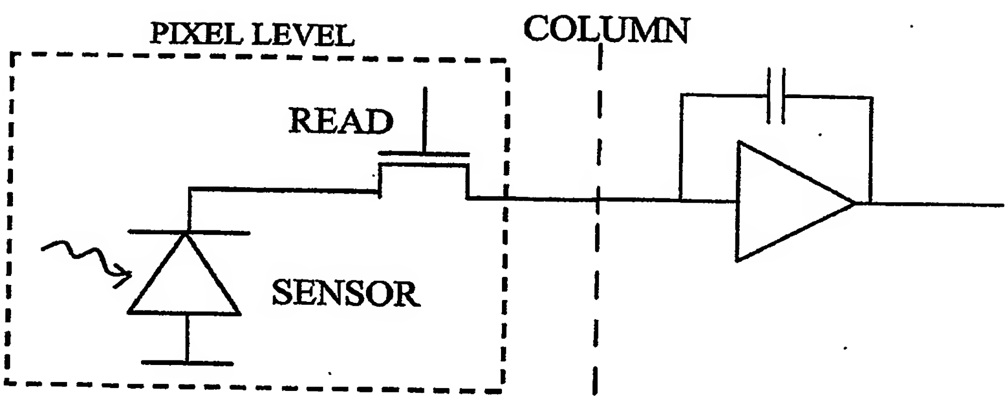

Figure 1

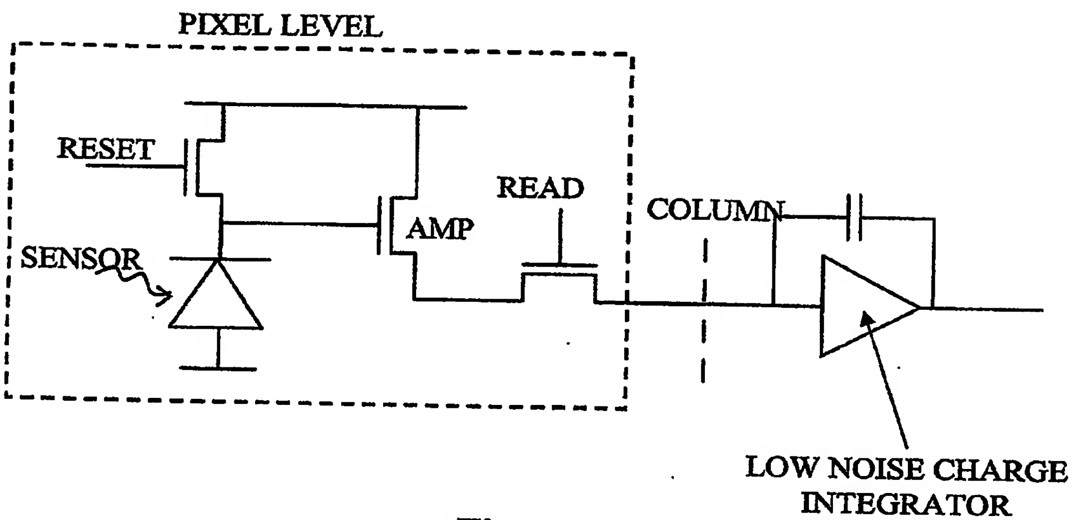
PIXEL LEVEL
RESET
SENSOR
AMP
READ
COLUMN
LOW NOISE CHARGE INTEGRATOR

Figure 2

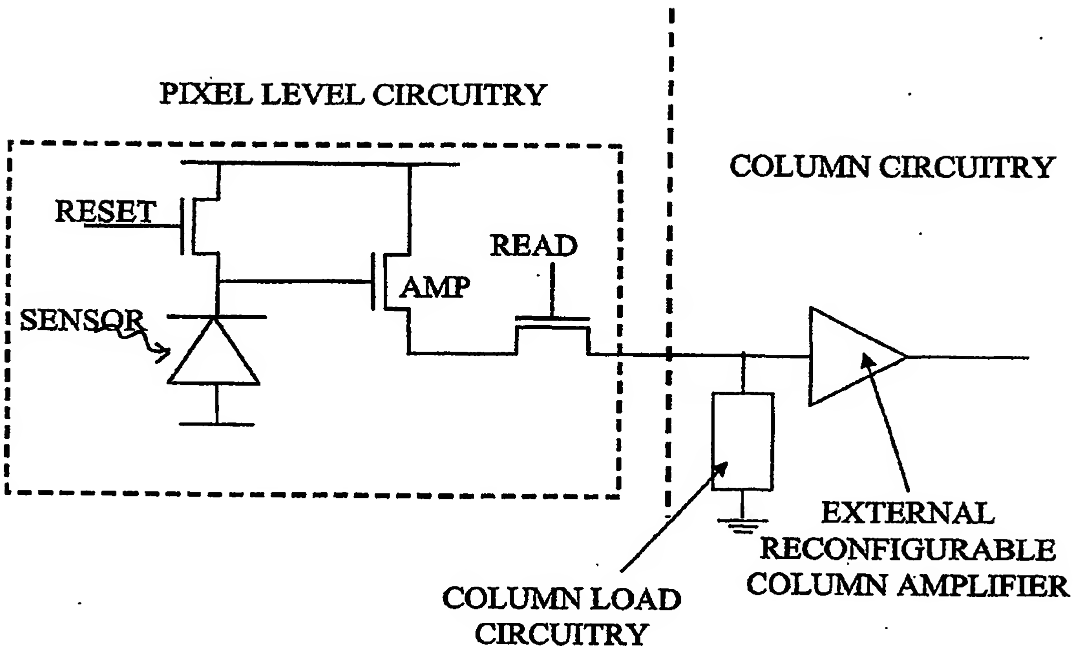
PIXEL LEVEL CIRCUITRY
COLUMN CIRCUITRY
RESET
READ
AMP
SENSOR
EXTERNAL
RECONFIGURABLE
COLUMN AMPLIFIER
COLUMN LOAD
CIRCUITRY

Figure 3

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